VII. *A Memoir, containing Obſervations of a Solar Eclipſe, October 27, 1780, made at* Beverly: *Alſo of a Lunar Eclipſe, March 29, 1782,—of a Solar Eclipſe, April 12, and of the Tranſit of Mercury over the Sun's Diſc, November 12, the ſame Year, made at the Preſident's Houſe in* Cambridge. *By the Rev.* Joseph Willard, *Preſident of the Univerſity.*

Obſervations of a ſolar eclipſe, October 27, 1780, at *Beverly.*

I ATTENDED to my clock for a number of days before the eclipſe, but more particularly on the 25th, 26th and 27th. On each of thoſe days, the ſtate of the atmoſphere was favourable for taking correſponding altitudes of the ſun. I took a number of double altitudes, both of his upper and lower limb, in the forenoon and afternoon, with *Hadley's* octant, by reflection from a bowl of very clear oil of tar, which was of ſuch a conſiſtence as to prevent undulation from the air, and in which, the ſolar image was extremely well defined. I noted the times by the clock, when the limbs of the two images of the ſun juſt came into contact. The conjunction of the centers I did not attempt to take, becauſe it cannot be determined with a certainty equal to the contact of the limbs.

The equation for the change of the ſun's declination, during the half interval between the forenoon and afternoon obſervations, was conſtantly applied.

Obſervations of correſponding double altitudes of the ſun, October 25.

	Foren. obſ.	Aftern. obſ.	Intervals.	½ Intervals.	Noon per clock nearly.
Sun's upper limb.	8h 35′ 2″	3h 22′ 46″	6h 47′ 44″	3h 23′ 52″	11h 58′ 54″
	8 39 40	3 18 8	6 38 28	3 19 14	11 58 54
	8 42 0	3 15 47	6 33 47	3 16 53½	11 58 53½
	8 44 23	3 13 25	6 29 2	3 14 31	11 58 54

	Foren. obs.	Aftern. obs.	Intervals.	½ Intervals.	Noon per clock nearly.
Sun's lower limb.	8h 50′ 46″	3h 7′ 5″	6h 16′ 19″	3h 8′ 9½″	11h 58′ 55½″
	8 55 32	3 2 16	6 6 44	3 3 22	11 58 54
	9 0 24	2 57 30	5 57 6	2 58 33	11 58 57
	9 2 48	2 55 8	5 52 20	2 56 10	11 58 58

Time of noon nearly by the clock, by a mean of the above eight obs.	11 58 55
Equation for change of declination in the ½ interval,	+ 16
Exact time by the clock, when ☉'s center passed the meridian,	11 59 11
Hence, the clock too slow for apparent time at noon,	49

In like manner observations were made on the 26th and 27th, the result of which it is sufficient to put down.

On the 26th,

When the sun's center passed the meridian, it was, by the clock, allowing for the equation,	11h 58′ 16″
Hence, the clock too slow for app. time at noon,	1 45

On the 27th,

When the sun's center passed the meridian, it was, by the clock,	11 57 18
Hence, the clock too slow for apparent time at noon, on the day of the eclipse,	2 42
Loss of the clock, respecting apparent time, between the noon of the 25th and 26th,	56
Ditto, 26th and 27th,	57

In the morning of the 27th, the Reverend Mr. *Cutler*, of *Ipswich*, and the Reverend Mr. *Prince*, of *Salem*, favoured me with their company, to observe the eclipse with me. Mr. *Cutler* and I were each furnished with a reflecting telescope, made by *Mann*, of *London*. The magnifying power of Mr. *Cutler's*, was 34, and that of mine, 45 times. Mr. *Prince's* telescope was an achromatic refractor of 3 feet. It's original magnifying power was 16½; but he increased it to 43 times, by taking out the third glass of the sliding-tube, and adding another eye-glass of

of about an inch focus. We determined the magnifying power of our telescopes by *Hawksbee's* method.

We sat down to our telescopes about ten minutes before eleven o'clock, in a garden adjoining the room where the clock was fixed, and were so situated, that we could all very distinctly hear the person who counted the clock. Before we began to observe, we agreed that each one should note his times of observation, without speaking to the others, that all might determine for themselves, and no one might be in danger of being disconcerted.

We had a favourable time for observing the beginning and end of the eclipse. The immersions and emersions of a number of the solar spots were attended to by us; the situations of which, upon the disc, we determined as near as we could, a little while before we sat down to our telescopes. They then appeared to us as in Plate II. Fig. II. Mr. *Prince* had fixed parallel hairs in his refractor, dividing the sun's disc into four equal parts, horizontally. These hairs, together with a vertical one in the center, assisted us much in settling the places of the spots.

As we had no micrometer to measure the magnitude of the eclipse, we determined it by Dr. *Wallis's* method, published in *Whiston's* Astronomical Lectures, p. 188, 189. The eclipsed parts of the sun, marked at the time of the greatest obscuration, we afterwards measured upon a diagonal scale drawn for the purpose, by which we could determine to the fiftieth part of a digit.

At the middle of the eclipse, and for some time before and after it, there was a very great chilness in the air, and so much dew fell, that the papers we used abroad became quite damp.

 The

The following are our observations of this eclipse, adjusted to apparent time.

	Mr. *Willard.*	Mr. *Cutler.*	Mr. *Prince.*
Beginning of the eclipse,	11h 1′ 48″	11h 1′ 42″	11h 1′ 46″
Immersions of the western edges of solar spots.			
No. 1, of the western spots,	11 22 31	11 22 28	11 22 41
No. 1, of the north-eastern spots,	11 33 31	11 33 23	11 33 25
No. 3, of ditto,	11 35 21	11 35 22	11 35 23
A large spot near the center,	11 36 56	11 36 54	11 36 57
A south-eastern spot nearest the vert. diam.		12 11 34	12 11 37
Emersions of the eastern edges of solar spots.			
No. 2, of the western spots,		12 31 55	12 31 56
No. 1, of the north-eastern spots,	12 53 50	12 53 47	12 54 4
No. 2, of ditto,	12 54 53	12 54 57	12 55 0
No. 3, of ditto,	12 55 36	12 55 36	12 55 41
No. 4, of ditto,	12 56 32	12 56 31	12 56 38
The large spot near the center,	12 58 6	12 58 4	12 58 14
The end of the eclipse,	1 41 26	1 41 23	1 41 29
The duration,	2 39 38	2 39 41	2 39 43

By our observation, the greatest obscuration was at about $12^h 21'$, apparent time, when the parts eclipsed were 11 dig. 24′

The clock's rate of going was the same for several days following the 27th, as it had been for the two days preceding.

N. B. 1. By twenty-seven double altitudes of the sun, when upon the meridian, taken with a *Hadley's* octant, very accurately constructed, I have found the latitude of the house, where the foregoing observations were made, 42° 36′ N.——The house stands facing the middle of the training-field, (so called) in the first parish in *Beverly*.

N. B. 2. By calculations from the observations of the foregoing eclipse made at *Beverly*, and those made at *Chelsea*, I find the difference of meridians to be 45″ in time; which, added to 26″, the difference between *Chelsea* and *Cambridge*, makes 1′ 11″ for the difference between *Cambridge* and *Beverly*. The difference between *Beverly* and *Penobscot*, where Professor *Williams* and company made their observations, I find, in the same way,

way, to be 8′ 4″, which makes the difference between *Cambridge* and *Penobſcot* 9′ 15″. The difference between *Beverly* and *Providence*, by deductions from the obſervations, is 2′ 18″, which gives 1′ 7″ between *Cambridge* and *Providence*.

Obſervations of a lunar eclipſe, March 29, 1782, made at the Preſident's houſe in *Cambridge*.

The going of my clock was aſcertained, for the obſerving of this eclipſe, in the ſame manner as for the foregoing one of October 27, 1780.

Mr. *Caleb Gannett* obſerved the eclipſe with me. The teleſcope I made uſe of was an achromatic refractor, with a magnifying power of 90. Mr. *Gannett* made uſe of a reflecting teleſcope, of about the ſame magnifying power. We had, upon the whole, a pretty favourable time; though the earth's ſhadow, at the moon, did not appear ſo well defined as we could have wiſhed.*

The obſervations follow.

		Apparent Time.	
		By Pref. *Willard.*	By Mr. *Gannett.*
Beginning of the eclipſe,		2^h 14′ 7″	2^h 14′ 0″ A. M.
Shadow touches	*Harpalus*,	22 51	22 57
	Tycho,	27 21	27 10
covers	*Tycho*,	29 16	29 4
touches	*Mare Criſium*,	3 28 49	3 28 10
leaves	*Mare Criſium*,	4 28 36	4 28 17
leaves	*Mare Tranquilitatis*,	33 40	34 7
End of the eclipſe,		4 53 50	4 53 33

Obſervations

* In obſervations of different lunar eclipſes, when the ſtate of the atmoſphere, as far as the eye could determine, has been the ſame, the earth's ſhadow has appeared much better defined in one, than in another.

Obſervations of a ſolar eclipſe, April 12, 1782, made at the Preſident's houſe.

The going of my clock was aſcertained in the ſame manner as at the time of the lunar eclipſe, in March.

Mr. *Caleb Gannett* and Mr. *William King* obſerved the eclipſe with me. Mr. *Gannett* and I had the ſame teleſcopes that we uſed for obſerving the lunar eclipſe. Mr. *King* was furniſhed with a good reflecting teleſcope, the magnifying power of which was about 40. At the beginning of the eclipſe the clouds were troubleſome; ſo that the entrance of the moon upon the ſun's limb was not ſeen by us, or by any of the obſervers in *Cambridge*. But the clouds diſperſed ſoon afterwards, and the atmoſphere became perfectly clear; ſo that we had a very favourable time for obſerving the end of the eclipſe, which was,

	Apparent Time.
By Preſident *Willard*, at	$2^h 51' 41''$ P. M.
Mr. *Gannett*,	2 51 27
Mr. *King*,	2 51 41

As we were not furniſhed with a micrometer, no other obſervations, of any conſequence, were made by us upon this eclipſe.

Obſervations of the tranſit of Mercury over the ſun's diſc, November 12, 1782, made at the Preſident's houſe.

The going of my clock was determined, for this phenomenon, as for the eclipſes, in the ſpring.

Mr. *Caleb Gannett* obſerved with me. We were furniſhed with the ſame teleſcopes that we made uſe of for obſerving the eclipſes. Our obſervations were as follow.

	Apparent Time.			
	1ſt ext. cont.	1ſt int. cont.	2d int. cont.	2d ext. cont.
By Pref. *Willard*,	$10^h 6' 27''$	$10^h 12' 37''$	$11^h 23' 2''$	$11^h 29' 32''$ A.M.
By Mr. *Gannett*,		10 12 45	11 23 36	11 29 29
Mean,		10 12 41	11 23 19	11 29 $30\frac{1}{2}$

	— $10^h\ 12'\ 41''$	— $10^h\ 6'\ 27''$
Duration of the tranſit,	internal 1 10 38	ext. 1 23 $3\frac{1}{2}$

The ſtate of the atmoſphere was unfavourable, during the tranſit. The limb of the ſun appeared ſerrated; ſo that it was difficult to determine the contacts, with that preciſion which could be wiſhed.

At the time of the firſt internal contact, and for ſome minutes after, the limb of ☿, next to the ſun's eaſtern limb, had an oval appearance; and his limb, next to the weſtern limb of the ſun, put on the ſame appearance, a few minutes before, and at the time of the ſecond internal contact.

For ☿'s horizontal parallax.

☿'s diſtance from the earth 67681 : the ſun's diſtance from the earth 98879 :: the ſun's horizontal parallax 8″, 55 : ☿'s horizontal parallax 12″, 49. Therefore, ☿'s horizontal parallax from the ſun is 3″, 94.

Elements for calculating ☿'s parallax from the ſun in latitude and longitude, at *Cambridge*, at the firſt external contact, November 12, 1782, at $10^{h}\ 6'\ 27''$, A. M. apparent time.

The ſun's longitude,*	$7^{S}\ 20^{\circ}\ 23'\ 53''$, 304
Mercury's geocentric longitude,	7 20 30 12, 078
Mercury's geocentric latitude, north,	14 55, 754
The ſun's right aſcenſion,	227 57 5
The right aſcenſion of the mid-heaven,	199 33 50
Angle anſwering to pPZ in Plate I. Fig. I.	70 26 10
The ſun's horary motion,	2 31, 2
Mercury's geo. hor. mot. in long. in the ecliptic retro.	3 22, 32

Mercury's

* The elements of the ſun are calculated from *Mayer's*, and thoſe of Mercury from M. de la *Lande's* tables.

Mercury's geo. hor. mot. from the sun in the eclipitc,		5′ 53″,	52
Mercury's geo. hor. motion in latitude increasing,		51,	96
The sun's semi-diameter,	16	12,	2
Mercury's semi-diameter,		5,	1
Mercury's horizontal parallax from the sun,		3,	94
The obliquity of the ecliptic,	23° 28	12	
The lat. of *Cambridge* reduced to the center,	42 8	37	

Hence,

The altitude of the nonagesimal degree,	44 24	32	
The longitude of the nonagesimal degree,	$5^{s.}$ 26 45	44	
Mercury's parallax in latitude from the sun,		2,	807
Mercury's parallax in longitude from the sun,		2,	224

At the second external contact, at $11^{h,}$ 29′ $30\frac{1}{2}$″, A. M. apparent time; by calculation,

Mercury's parallax in latitude from the sun,	3,	169
Mercury's parallax in longitude from the sun,	1,	280

The longitude of the nonagesimal degree, at the time both of the first and second external contact, being less than the longitude of Mercury, the parallax in longitude is to be added to Mercury's longitude, in each, to give the visible; and as Mercury's motion in transits is retrogade, and the parallax at the time of the second external contact was greater than at the time of the first, the length of the visible transit-line was greater than the true, by the difference of the parallaxes.

The true latitude, at each contact, was diminished by the parallax in latitude; and as the geocentric latitude was increasing, and the parallax, at the time of the second external contact, greater than at the time of the first, the visible motion in latitude was less than the true, by the difference of the parallaxes.

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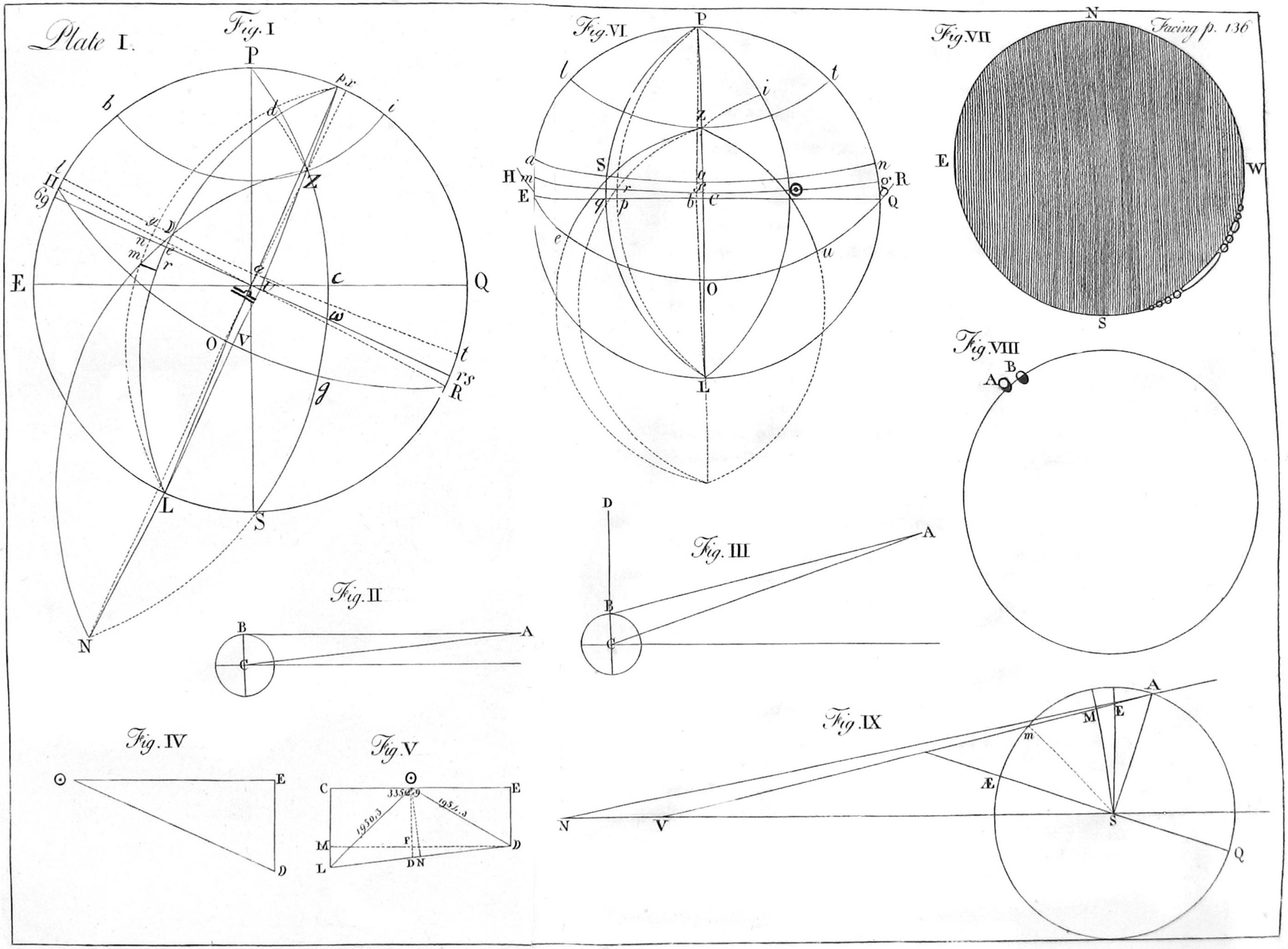
Plate I.



☿'s parallax in longitude from ☉, 1st ext. cont.		2'',224
Ditto,	2d,	1, 280
Difference,		0, 944
☿'s parallax in latitude from ☉,	1st,	2, 807
Ditto,	2d,	3, 169
Difference,		0, 362
☿'s true mot. on ☉'s disc in $1^{h.}\ 23'\ 3\frac{1}{2}''$ reduc. to the ecl.		8' 9, 376
Difference of parallaxes in longitude,		+ 0, 944
Length of the vis. transit-line reduced to the ecliptic,		8 10, 320
		= 490'', 32.
☿'s true motion in latitude in $1^{h.}\ 23'\ 3\frac{1}{2}''$,		1 11, 928
Difference of parallaxes in latitude,		— 0, 362
Visible motion in latitude,		1 11, 566
		= 71'', 566

For the angle of Mercury's visible way with the sun in the ecliptic; the error of the tables in latitude; and the time of the ecliptic conjunction of ☉'s and ☿'s centers, deduced from the times of the external contacts.

In Plate II. Fig. III. let EDK represent half of the sun's disc; the diameter E☉K a portion of the ecliptic, or rather a parallel to it;* ☿U a parallel = 490'', 32 Mercury's visible motion upon the sun's disc, reduced to the ecliptic; UM Mercury's visible motion in geocentric latitude, during the time between the two external contacts; consequently, M☿U, the angle required, and ☿M the visible transit-line; the point ☉ the sun's center, at the apparent time of the visible conjunction of centers; ☉N, perpendicular to ☿M, the visible least distance of centers; ☉D perpendicular to the ecliptic, the visible dis-

S tance

* The distance from the ecliptic being equal to the sun's parallax in latitude.

tance of centers, at the time of the visible ecliptic conjunction; ☿⊙ and M⊙ the distance of centers, at the time of the external contacts, = the sum of the semi-diameter of the sun and of Mercury = 977″, 3; C☿ the visible difference of latitude of the centers, at the time of the first external contact; LM the visible difference, at the time of the second; C⊙ = ☿F the visible difference of longitude of the centers, at the time of the first; and ⊙L at the time of the second external contact.

For M☿U, the angle of Mercury's visible way.

☿U 490″, 32 : UM 71″, 566 :: Radius : Tangent angle M☿U 8° 18′ 15″.

For ☿M, the visible transit line.

Sine M☿U 8° 18′ 15″ : UM 71″, 566 :: Radius : ☿M 495″, 512. As ☿⊙ and M⊙ are equal, the perpendicular ⊙N bisects ☿M; therefore, ☿N and NM are 247″, 756 each.

For angle ☿⊙N.

⊙☿ 977″, 3 : Radius :: ☿N 247″, 756 : Sine angle ☿⊙N 14° 41′ 7″. Add angle N⊙D = M☿U 8° 18′ 15″, the sum is = angle ☿⊙D = ☿⊙F = ⊙☿C = 22° 59′ 22″; the complement of which is = angle ☿⊙C = 67° 0′ 38″.

For side C☿ = Mercury's visible latitude from sun, at the first external contact.

Radius : ⊙☿ 977″, 3 :: Sine angle ☿⊙C 67° 0′ 38″ : C☿ 899″, 68 = 14′ 59″, 68; to which add the parallax in latitude 2″, 807, and the sum 15′ 2″, 487 is Mercury's true latitude by observation, at the time of the first external contact.

For side C⊙, the visible difference of longitude of the centers of the sun and Mercury, at the time of the first external contact.

Radius : ⊙☿ 977, 3 :: Sine angle ⊙☿C 22° 59′ 22″ : C⊙ = ☿F 381″, 696; from which subtract 2″, 224, Mercury's

parallax

parallax in longitude from the ſun, becauſe his viſible longitude was greater than the true, and the remainder, 379″, 472, will be the true difference of longitude.

For the apparent time of the true ecliptic conjunction, and Mercury's true latitude by obſervation.

Mercury's ecliptic horary motion upon ☉'s diſc 353″, 52 : 1ʰ· = 3600″ :: the true difference of longitude 379″, 472 : 3864¼″, the ſpace of time from the firſt external contact to the ecliptic conjunction, = 1ʰ· 4′ 24¼″; which, added to 10ʰ· 6′ 27″, gives 11ʰ· 10′ 51¼″, for the apparent time of the true ecliptic conjunction.

In 1ʰ· 4′ 24¼″, Mercury's geocentric latitude was encreaſed 55″, 774; which, added to 15′ 2″, 487, his latitude at the firſt external contact, makes 15′ 58″, 261, for Mercury's true latitude by obſervation, at the time of the true ecliptic conjunction, by the external contacts.

Deductions from the internal contacts.

Let the references be to Plate II. Fig. III. the lines ☉☿ and ☉M being ſuppoſed = the difference of the ſemi-diameters of the ſun and Mercury = 967″, 1; and, conſequently, the tranſit-line wholly within the ſun's diſc.

☿'s parallax in longitude from ☉,	1ſt int. cont.	2″, 158
Ditto,	2d,	1, 355
Difference,		0, 803
☿'s parallax in latitude from ☉,	1ſt,	2, 837
Ditto,	2d,	3, 145
Difference,		0, 308

☿'s true mot. on ☉'s disc in $1^{h.}$ 10′ 38″ reduc. to the ecli.	6′ 56″, 171
Difference of parallaxes in longitude,	+ 0, 803
Length of the vis. transit-line reduced to the ecliptic,	6 56, 974
	= 416, 974
☿'s true motion in latitude in $1^{h.}$ 10′ 38″,	1 1, 168
Difference of parallaxes in latitude,	— 308
Visible motion in latitude,	1 0, 86
	= 60, 86

Hence,

M☿U, the angle of Mercury's visible way 8° 18′ 15″; — ☿M, the visible transit-line, 421″, 392;—angle ☿☉N 12° 35′ 1″, consequently, ☿☉D = ☿☉F = ☉☿C 20° 53′ 16″, and angle ☿☉C 69° 6′ 44″;—side C☿, Mercury's visible latitude from the sun, at the time of the first internal contact, 903″, 543 = 15′ 3″, 543; which, added to the parallax in latitude from the sun, 2″, 837, gives 15′ 6″, 38, for Mercury's true latitude by observation, at the time of the first internal contact; —the side C☉, the visible difference of longitude of the centers of the sun and Mercury, 344″, 809; which, lessened by the parallax in longitude from the sun, 2″, 158 gives 342″, 651 for the true difference of longitude; which, converted into time, gives 58′ 9½″. This added to $10^{h.}$ 12′41″, A. M. gives $11^{h.}$ 10′ 50½″, for the apparent time of the true ecliptic conjunction.

In 58′ 9½″, Mercury's geocentric latitude was increased 50″ 365; which, added to 15′ 6″, 38, his latitude at the first internal contact, gives 15′ 56″, 745, for Mercury's true latitude by observation, at the time of the true ecliptic conjunction, by the internal contacts.

The

The apparent time of the true ecliptic conjunction, by the external contacts, being $11^{h.}\ 10'\ 51\frac{1}{4}''$, and by the internal ones $11^{h.}\ 10'\ 50\frac{1}{2}''$, let us call the time $11^{h.}\ 10'\ 51''$, when Mercury's latitude, by the former, muſt have been $15'\ 58''$, 257, and by the latter, $15'\ 56''$, 752, the mean of which, $15'\ 57''$, 504, may be called Mercury's true latitude by obſervation, at the time of the ecliptic conjunction. By M. de la *Lande's* tables it was $15'\ 51''$, 524; ſo that the error in the tables, by this mean, is $-\ 5''$, 98.

For Mercury's heliocentric latitude, according to the obſerved geocentric latitude.

Mercury's diſtance from the ſun, 31198 : Mercury's diſtance from the earth 67681 :: Mercury's geocentric latitude at the ecliptic conjunction, by obſervation, $15'\ 57''$, $504 = 957''$, 504 : Mercury's heliocent. lat. by obſervation, $2077''$, $2 = 34'\ 37''$, 2.

For the place of the aſcending node by obſervation.

Let ☊E, in Plate II. Fig. IV. be a portion of the ecliptic; the point ☊ the place of ☿'s aſcending node; ☊☿ a portion of ☿'s heliocentric orbit; the point at ☿ his heliocentric place in his orbit, at the time of the ecliptic conjunction, and E his place reduced to the ecliptic; E☿ his heliocentric latitude; the angle E☊☿ the inclination of his orbit, by modern Aſtronomers generally determined to be $7°\ 0'\ 0''$. In the right-angled ſpheric triangle E☊☿, right-angled at E, there are given the angle E☊☿, and the perpendicular or ſide E☿, to find the baſe or ſide ☊E.

	Radius,				
:	Tang. E☿ or ☿'s heliocentric lat.	34'	37'', 2		8 0030458
::	Tang. Co-inclination ☿'s orbit,	83°	0	0	10 9108562
:	Sine baſe ☊E or ☿'s diſt. from aſc. node,	4	42	16	8 9139020

As

As Mercury's heliocentric motion was in the order of the ſines, and he had paſſed the node, ſubtract this diſtance from his heliocentric longitude, and the remainder will be the point ☊ of the ecliptic, or place of Mercury's aſcending node.

Mercury's heliocentric longitude,	1^{s}	$20°$	$26'$	$36''$
Subtract ☿'s diſtance from ☊,		4	42	16
Place of ☿'s aſcending node by obſervation,	1	15	44	20
Ditto by M. de la *Lande's* tables,	1	15	45	54